PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re the Application of

Pettitt (TI-28576) Conf. No. 2019

Serial No. 09/945,295 Group Art Unit: 2624

Filed: August 31, 2001 Examiner: Hung

For: Automated Color Matching for Tiled Projection System

DECLARATION OF GREGORY S. PETTITT

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

I, Gregory S. Pettitt, hereby declare:

1. I am the named inventor in this patent application.

2. I have been employed by Texas Instruments Incorporated, in Dallas, Texas, since at least as early as August 17, 1999.

3. Exhibit A to this Declaration is a true and correct copy of a patent disclosure prepared by me, in the United States, and submitted to the Patent Department of Texas Instruments Incorporated. This patent application, S.N. 09/945,295, was prepared from this patent disclosure. I prepared this patent disclosure at least as early as August 17, 1999. This patent disclosure was read and understood by others, in the United States, at least as early as August 17, 1999, as evidenced by their signatures on the last page. On information and belief, this patent disclosure was received by the Patent Department of Texas Instruments Incorporated

at least as early as August 17, 1999, as indicated by the "Received" stamp on each page of this patent disclosure.

4. The invention described in the patent disclosure of Exhibit A, and described in this patent application S.N. 09/945,295, has been embodied into a hardware function and embedded software in at least one application-specific integrated circuit (ASIC) manufactured and sold by Texas Instruments Incorporated. One such ASIC is referred to as the DDP 1000 DMD Controller, and has been used and sold in the United States.

5. Efforts and activity toward design and manufacture of the DDP 1000 DMD Controller began in the United States at least as early as February 10, 2000, and were continuing in the United States from at least as early as February 10, 2000 until successful manufacture of the DDP 1000 DMD Controller, and testing of that ASIC in the United States.

6. Exhibit B to this Declaration is a slide, dated February 20, 2002, which was shown and displayed to personnel of Texas Instruments Incorporated in the United States. This slide of Exhibit B indicates that efforts toward design and manufacture of the DDP 1000 DMD Controller began at least as early as February 10, 2000, and continued to the manufacture of prototypes.

7. Exhibit C to this Declaration is a slide, dated earlier than February 10, 2000, which was shown and displayed to personnel of Texas Instruments Incorporated in the United States. This slide of Exhibit C indicates the status of efforts toward the design and manufacture of the DDP 1000 DMD Controller, and specifically indicates that the VHDL Code, initial synthesis, and modeling of the PCC block was complete at that time. The PCC block of the DDP 1000 DMD Controller is a hardware function that, in combination with embedded software, embodies the invention described in the patent disclosure of Exhibit A and described and claimed in this patent application S.N. 09/945,295.

8. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United

States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Gregory S. Pettitt

Gregory S. Pettitt

Date: 09/10, 2007

EXHIBIT A

DOCKET NO. TI 28576

2040
CAB

1. **Please suggest a descriptive name for your invention:**

Automated color correction of tiled projection systems

2. **What is the problem solved by your invention?**

Current tiled or video wall systems must be individually measured and adjusted in order to match color and brightness of each projector. Many current systems adjust only the white of the system, as it would take to long too perform a measure of red, green, blue and white. But as the tiled or video wall systems pursue enhanced performance, the complete color and brightness correction of the walls must be included.

3. **What is your solution to the problem?**

Each DLP DME engine is measured and calibrated as it is using the 2-bit RGBY algorithm. In the process of these measurements, certain information about the colorimetry of the engine can be determined. The current color wheels for these engines contain an EPROM, in which the calibration information for the engines are stored. This information is derived from color measurements of the engine. The following is the calibration equations used in the DME setup. From these equations, the information needed for the adjustment of the colorimetry is found. This information is contained in the engine's system transfer function matrix, M.

The signal flow diagram of a typical engine is shown in Figure 1. The first color space conversion (CSC1) matrix is used to convert from the YCrCb color space to RGB. The degamma function removes the gamma from the signal. The RGB signal is now in a linear space. The RGBY gain is applied to the signal, then the second color space conversion (CSC2) matrix is used to convert the gained RGB signal to the color corrected color space, thus providing a match between engines. The feedback between RGBY and CSC2 provides a mechanism to improve color correction given the use of white peaking.

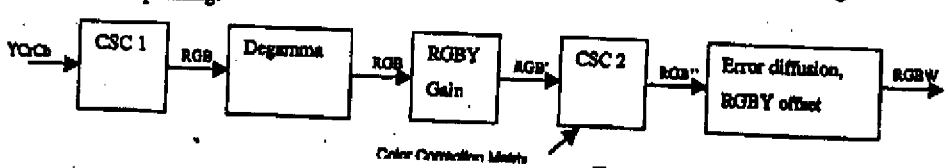


Figure 1

The engine color correction is accomplished using the system transfer function matrices. Each engine transfers it's transfer matrix, M^j, to a master controller, and the CSC2 needed for each engine is calculated. Additional information on the luminance level of each engine is also provided.

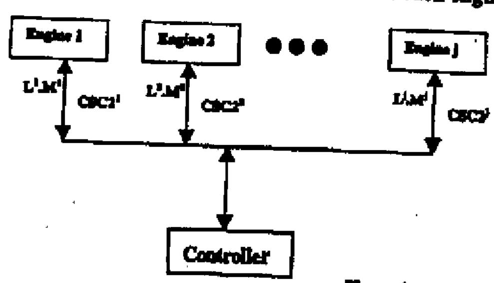


Figure 2

RECEIVED
[redacted]
TI PATENT DEPT

RGBY Calibration equations

Step 1: Measure chromaticities and luminance's at one standard wheel rate.

PR650	Luminance
X_R, Y_R, Z_R	Y'_{RGB}
X_G, Y_G, Z_G	Y'_{WS}
X_B, Y_B, Z_B	
X_{WS}, Y_{WS}, Z_{WS}	

Define: $X_{RGB} = X_R + X_G + X_B$

$Y_{RGB} = Y_R + Y_G + Y_B$

$Z_{RGB} = Z_R + Z_G + Z_B$

Using ELT's from standard wheel rate: $ELT^S_R, ELT^S_G, ELT^S_B, ELT^S_{WS}$

then each of the XYZ measurements for each color can be adjusted for additional wheel rates:

$$X^N{}_\phi = X_\phi \cdot \frac{ELT^N_\phi}{ELT^S_\phi} \qquad Y^N{}_\phi = Y_\phi \cdot \frac{ELT^N_\phi}{ELT^S_\phi} \qquad Z^N{}_\phi = Z_\phi \cdot \frac{ELT^N_\phi}{ELT^S_\phi}$$

where

$\phi = R, G, B, WS$

ELT^S_ϕ is the standard wheel rate ELT for a given color ϕ

ELT^N_ϕ is the ELT for wheel rate N for a given color ϕ

and $X^N{}_\phi, Y^N{}_\phi, Z^N{}_\phi$ are the new adjusted measurement for the given wheel rate N

each of the steps is then carried out for each wheel rate.

Step 2: Find α and β, and compute white segment colorimetry

$$\alpha = \frac{Y'_{RGB} \cdot Y_{WS}}{Y'_{WS} \cdot Y_{RGB}} \qquad \beta = \frac{Y'_{WS}}{Y'_{RGB}} \quad (y-ratio)$$

$$X''_{WS} = \alpha \cdot X_{WS} \qquad Y''_{WS} = \alpha \cdot Y_{WS} \qquad Z''_{WS} = \alpha \cdot Z_{WS}$$

Step 3: Form sums and matrix

$S_R = X_R + Y_R + Z_R$ $\qquad S_{RGB} = X_{RGB} + Y_{RGB} + Z_{RGB}$

$S_G = X_G + Y_G + Z_G$ $\qquad S_{WS} = X''_{WS} + Y''_{WS} + Z''_{WS}$

$S_B = X_B + Y_B + Z_B$

$$A = \begin{bmatrix} \frac{X_R}{S_R} & \frac{X_G}{S_G} & \frac{X_B}{S_B} \\ \frac{Y_R}{S_R} & \frac{Y_G}{S_G} & \frac{Y_B}{S_B} \\ \frac{Z_R}{S_R} & \frac{Z_G}{S_G} & \frac{Z_B}{S_B} \end{bmatrix}$$

<u>Step 4: Find inverse of A</u>

$$\textit{Define}:\quad A=\begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix}$$

Then

$$A^{-1}=Dt\cdot\begin{bmatrix} e\cdot i-f\cdot h & c\cdot h-b\cdot i & b\cdot f-c\cdot e \\ f\cdot g-d\cdot i & a\cdot i-c\cdot g & c\cdot d-a\cdot f \\ d\cdot h-e\cdot g & b\cdot g-a\cdot h & a\cdot e-b\cdot d \end{bmatrix}$$

$$Dt=\frac{1}{(a\cdot e\cdot i-a\cdot f\cdot h-d\cdot b\cdot i+d\cdot c\cdot h+g\cdot b\cdot f-g\cdot c\cdot e)}$$

<u>Step 5: Form normalized white points</u>

$$W_X={}^{X_{RGB}}\!\big/_{Y_{RGB}} \qquad WS_X={}^{X''_{WS}}\!\big/_{Y''_{WS}}$$

$$W_Y=1 \qquad WS_Y=1$$

$$W_Z={}^{Z_{RGB}}\!\big/_{Y_{RGB}} \qquad WS_Z={}^{Z''_{WS}}\!\big/_{Y''_{WS}}$$

$$\textit{Define}:\quad A^{-1}=\begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix}$$

$$K_R=W_X\cdot a+b+W_z\cdot c$$
$$K_G=W_X\cdot d+e+W_z\cdot f$$
$$K_B=W_X\cdot g+h+W_z\cdot i$$

$$Q_R=WS_X\cdot a+b+WS_z\cdot c$$
$$Q_G=WS_X\cdot d+e+WS_z\cdot f$$
$$Q_B=WS_X\cdot g+h+WS_z\cdot i$$

<u>Step 6: Compute engine calibration parameters</u>

$ccr = Q_R / K_R$

$ccg = Q_G / K_G$

$ccb = Q_B / K_B$

$offset1 = 1/3 \cdot 255 \cdot \beta - 0.5$

$offset2 = 2/3 \cdot 255 \cdot \beta - 0.5$

$offset3 = 3/3 \cdot 255 \cdot \beta - 0.5$

$Ymin = 64;$

$Roffset1 = \lfloor ccr \cdot offset1 + 0.5 \rfloor$

$Roffset2 = \lfloor ccr \cdot offset2 + 0.5 \rfloor$

$Roffset3 = \lfloor ccr \cdot offset3 + 0.5 \rfloor$

where $\lfloor\ \rfloor$ is the truncate operator

$Goffset1 = \lfloor ccg \cdot offset1 + 0.5 \rfloor$

$Goffset2 = \lfloor ccg \cdot offset2 + 0.5 \rfloor$

$Goffset3 = \lfloor ccg \cdot offset3 + 0.5 \rfloor$

$Boffset1 = \lfloor ccb \cdot offset1 + 0.5 \rfloor$

$Boffset2 = \lfloor ccb \cdot offset2 + 0.5 \rfloor$

$Boffset3 = \lfloor ccb \cdot offset3 + 0.5 \rfloor$

$ythres1 = \lfloor 255 + \min(Roffset1, Goffset1, Boffset1) + 0.5 \rfloor$

$ythres2 = \lfloor 255 + \min(Roffset2, Goffset2, Boffset2) + 0.5 \rfloor$

$$ygain = \left[\frac{255 * (1+\beta) - y\min}{(255 - y\min)} \right] - 1$$

RECEIVED
[redacted]
TZ PATENT DEPT

Step 7: Compute the system transfer function matrix

$$M = \begin{bmatrix} a & b & c & d \\ e & f & g & h \\ i & j & k & l \end{bmatrix}$$

(Note: these are not the same as in step 5)

$$F_R = K_R / (S_R \cdot ELT_R)$$

$$F_G = K_G / (S_G \cdot ELT_G)$$

$$F_B = K_B / (S_B \cdot ELT_B)$$

$$F_{WS} = K_{WS} / (S_{WS} \cdot ELT_{WS})$$

$$a = F_R \cdot X_R \qquad b = F_G \cdot X_G \qquad c = F_B \cdot X_B \qquad d = F_{WS} \cdot \frac{X''_{WS}}{Y''_{WS}}$$

$$e = F_R \cdot Y_R \qquad f = F_G \cdot Y_G \qquad g = F_B \cdot Y_B \qquad h = F_{WS}$$

$$i = F_R \cdot Z_R \qquad j = F_G \cdot Z_G \qquad k = F_B \cdot Z_B \qquad l = F_{WS} \cdot \frac{Z''_{WS}}{Y''_{WS}}$$

Store the RGBY calibration parameters, the matrix M and the ELT's for R,G,B,WS in the color wheel EPROM.

The matrix M and the ELT's for the system define the complete colorimetry of the system. The only remaining variable is the luminance. Each engine now has it's own colorimetry stored with the colorwheel, and given the luminance, the color correction needed to match each engine can be computed.

Given a cube of engines to be matched, the engines could be polled to get each engine's matrix, M^i. These could be collected by a master engine, or by an external DSP card, or by an external PC controller.

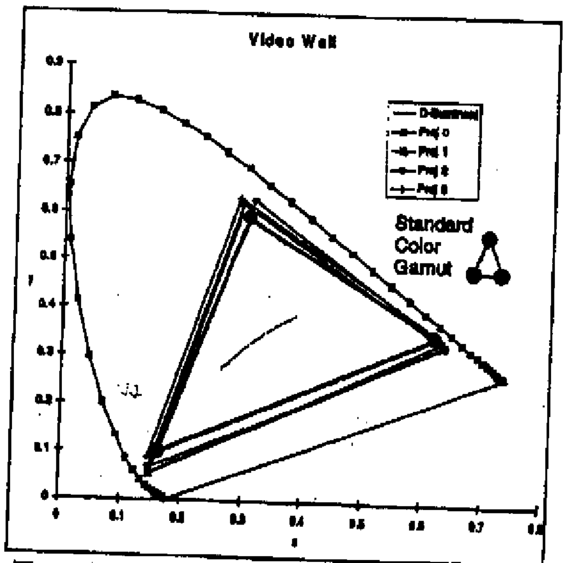
The next step will be to compute the new color gamut which will be used as the standard to adjust all the engines to. This can be accomplished by finding the largest color gamut triangle which is contained within the color gamut of all the engines. This color gamut can be found by pairing two engines, finding the largest color gamut which is contained within their color gamut. This new color gamut is then paired with all other engines, and a new gamut established from each pairing.

RECEIVED

[redacted]

Once found, this new standard color gamut is then used to be the standard to which all projectors are adjusted. The standard color gamut is used to calculate the color correction matrix for each engine. This is accomplished using the following mathematical structure.

Find the standard projector system matrix, M_r, using the techniques of step 5 and step 7. The white of the standard projector can be define as either the average white point of all engines or as an arbitrary white point.



Then using the projector j system matrix:

$$M_j = \begin{bmatrix} a & b & c & j \\ d & e & f & k \\ g & h & i & l \end{bmatrix}$$

we find the inverse of the RGB portion of the matrix:

$$Define: \ C = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix}$$

Then

$$C^{-1} = Dt \cdot \begin{bmatrix} e \cdot i - f \cdot h & c \cdot h - b \cdot i & b \cdot f - c \cdot e \\ f \cdot g - d \cdot i & a \cdot i - c \cdot g & c \cdot d - a \cdot f \\ d \cdot h - e \cdot g & b \cdot g - a \cdot h & a \cdot e - b \cdot d \end{bmatrix}$$

RECEIVED
[redacted]
TX PATENT DEPT

$$Dt = \frac{1}{(a \cdot e \cdot i - a \cdot f \cdot h - d \cdot b \cdot i + d \cdot c \cdot h + g \cdot b \cdot f - g \cdot c \cdot e)}$$

$$E_j = \begin{bmatrix} ELT_R^N & 0 & 0 \\ 0 & ELT_G^N & 0 \\ 0 & 0 & ELT_B^N \end{bmatrix}$$

$$[E_j]^{-1} = \begin{bmatrix} 1/ELT_R^N & 0 & 0 \\ 0 & 1/ELT_G^N & 0 \\ 0 & 0 & 1/ELT_B^N \end{bmatrix}$$

where N is the given wheel rate.

The color correction matrix for engine j, is given by:

$$CM_j = [E_j]^{-1} \cdot C_j^{-1} \cdot C_T \cdot E_T$$

This matrix can now be downloaded into engine j, and will correct all colors into the gamut defined by $C_T \cdot E_T$. This process can be repeated for each engine in the cube. The engines will now be color corrected, each having the same color gamut.

The next issue will be the luminance levels of the engines. Following color correction of each engine, the luminance level of each engine must be matched. This can be accomplished using either a direct measurement of each engine, or through use of a sensor internal to each engine. This internal sensor could be a sensor placed in the dump light path or other suitable location in which the light is proportional to the lamp output. This sensor could be calibrated in the factory to read a number related to the luminance level of the engine. This luminance level of the each engine would then be used to adjust the gain levels of the RGB matrix.

Additionally, information about the screen color performances could be input into the controller and color correction for screen colorimetric performance could be performed. This could include correction for reduced blue saturation, or general white point movement due to the screen.

As shown in figure 2, the color correction is directed using a master controller. This controller could be a TI DSP, a microcontroller, or an external computer such as a PC, or workstation. The master control processor would be placed within a bus structure which could communicate with each engine, polling for the needed system color transfer matrices, and then returning the color correction matrix. Additionally, the controller could communicate with customer interfaces, and provide inputs for adjustment of the white point of the system, or provide outputs of the lamp status of each engine, (using the luminance data collected from each engine). This could give the customer advanced warning to the need to replace a lamp prior to lamp failure.

The concepts outlined in this disclosure are not only applicable to DLP system using the digital micromirror device (DMD), but are also applicable to other display technologies. These include, but are not limited to, LCD (transmissive, reflective, etc.) , plasma, CRTs, FEDs, laser illumination systems, or led illumination systems. The concepts are also applicable to both rear and front projection display technologies and is not limited to multiple display systems. This concept provides an automatic color management scheme for display technology.

4. When was your solution first conceptually or mentally complete?

[redacted]

5. What is the first tangible evidence of such completion?

This document.

6. What is different about your solution, compared with other solutions to the same problem?

Current systems do not have any information stored which predicts the colorimetry of the projection systems. Therefore, a manual solution is utilized which requires the measurement of each projector, then the computation of each. Many times only the white point is measured which allows only the white point to be matched. With this solution, all color points could be corrected, and no measurements would need to be performed.

7. What are the advantages of your solution?

This process would provide differentiation between the DLP solutions and other projection technology solutions.

8. What TI products, process, projects or operations currently implement your invention?

None.

9. What is the date of first implementation?

No implementation of the idea has been worked on yet, but a spreadsheet simulation of the idea is anticipated.

10. What record exists to prove this date?

N/A

11. Is there any future implementation planned?

Yes, in a spreadsheet simulation of the system.

12. Has the invention been published or disclosed to anyone outside TI (Y/N)

No.

RECEIVED [redacted] TI PATENT DEPT

13. Has a TI product incorporating the invention been publicly introduced, quoted, sampled or shipped? (Y/N)

No

When? If planned -- when?

14. Was the invention conceived or first implemented in the performance of a government contract or subcontract? (Y/N) Contract #________________

No

THE INVENTION DESCRIBED BY THIS DISCLOSURE IS SUBMITTED PURSUANT TO MY EMPLOYMENT WITH TEXAS INSTRUMENTS INCORPORATED OR A TI SUBSIDARY (SPECIFY):

IS THIS A CONFIRMATION OF A PRIOR DISCLOSURE TO THE PATENT DEPARTMENT? (Y/N) No

(Signed) Gregory S. Pettitt [redacted] 8477

Date Mail Station

(Printed) Inventor: ____Gregory Pettitt____________________

Home Address: ____9202 Briarcrest____________________

______Rowlett, TX 75088____________________

Employee#: _181599___ TI Group/Division/Dept. _DIVP_/_04_/_2400_

Phone#: 972-575-0012 (work) 972-412-4499 (home) Country of Citizenship: USA

(Signed)____________________________ _________ _________

Date Mail Station

(Printed) Inventor: ____________________

Home Address: ____________________

____

Employee#: _________ TI Group/Division/Dept. _DIVP_/_04_/_____

Phone#: ____________________________ Country of Citizenship: ____

This invention disclosure with any attachments was read and understood by me on [redacted]

Marc Pyne [redacted]

Witness Date

This invention disclosure with any attachments was read and understood by me on [redacted]

[illegible] [redacted]

Witness Date

RECEIVED [redacted] TI PATENT DEPT

EXHIBIT B

DLP
A TEXAS INSTRUMENTS TECHNOLOGY

DDP1000 Milestone Summary

- Summary of Netlist Processing Milestones:
  - <u>Planned</u> <u>Actual</u>
  - [redacted] - Initial Req'ments Spec
  - [redacted] - First Analysis Netlist
  - 04/25/00 - Floorplan Netlist # 1
  - 06/06/00 - Floorplan Netlist # 2
  - 08/01/00 - Preliminary Netlist
  - skipped - Production* Netlist
  - skipped - RTL
  - 11/20/00 - RTC
  - 12/14/00 - RTM
  - 02/14/01 - First Prototypes

* Altered plan to skip production netlist and just use Preliminary

EXHIBIT C

DLP
A TEXAS INSTRUMENTS TECHNOLOGY

DDP1000 Development Status

VGP Blocks	Engr	Spec	VHDL Code	Initial Synth	Initial Rel	Model	Stim files	Test Matrix	Test Sim
VGP						wip			
TPG	JF	A	**A-cmplt**	**A-cmplt**		**wip**			
DSC	JF	A	A-cmplt	**A-cmplt**		A-cmplt			
BHT	JF	A	A-cmplt	**A-cmplt**		A-cmplt			
NRF	JF	A*	xxx			A-cmplt			
BWE	JF	B	**B-cmplt**	**B-cmplt**		B-cmplt			
CHI	MP	A	**wip**			A-cmplt			
SHP	MP	A	xxx			A-cmplt			
CTI	MP	A	xxx			A-cmplt			
CSC	MP	A	A-cmplt	**A-cmplt**		A-cmplt			
GAM	MP	A	A-cmplt	**A-wip**		A-cmplt			
PCH	JF	A	A-cmplt	**A-cmplt**		A-cmplt			
HCY	MP	B	B-cmplt	**B-wip**		B-cmplt			
PCC	JF	A	**A-cmplt**	**A-cmplt**		A-cmplt			
EDF	MP	A	A-cmplt	**A-cmplt**		A-cmplt			
SCB	MP	A	A-cmplt	**A-wip**		A-cmplt			

* Change pending

[redacted] WJS